Operational and Interpretation Challenges in Horizontal Well Production Logging: Examples from the Panna Field, Western Offshore, India.

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Abstract

New technologies have enabled the drilling of a number of multilateral wells for maximum reservoir contact (MRC) with segmented liner completions to effectively isolate water/gas producing sections. Whilst the construction of MRC wells is clearly the way forward in oil-rim fields, production logging to identify water / gas ingress points has proved challenging in such environments. Many attempts in the past using both coil tubing and tractor as a conveyance mechanism have not proved very successful in either cased or open hole completions, due to various operational constraints.

This case study discusses the first successful horizontal well production logging campaign done in Panna, an oil rim field offshore India. The tool string used for the campaign included the new generation tools like the multi-point multiphase hold-up tools, in addition to the conventional production logging sensors, and was conveyed on coil tubing. The main objectives of the campaign were to diagnose well production problems, evaluate the effectiveness of the new completion design, determine the drawdown along the drain hole and provide data to optimize the productivity of future and existing wells. This paper reviews the entire Production Logging Campaign with special emphasis on the operational and interpretation challenges that were faced during the course of the campaign.

Further to this, the paper also discusses the operational challenges in the second phase of the campaign where a wireline tractor was employed as a conveyance mechanism for the advantage of extended reach and real-time data monitoring.

Introduction

The Panna field is located 95 km north-west of the city Mumbai in the Bombay basin of offshore India and is on production since 1986. The location map of Panna is shown in Figure-1a. Panna is essentially a heterogeneous limestone reservoir with in-place volumes of about 1200 million barrels of oil and 2.9 TCF of gas. The principal hydrocarbon bearing formations in Panna Field are the Middle Eocene Bassein B Upper and the Early Eocene Bassein A limestone with a thin oil rim of ~20m, sandwiched between an overlying gas cap and large aquifer below. A structural cross-section of the Panna field is depicted in Figure 1b.

An unconformity representing approximately 4 million years of Upper Eocene time separates the Bassein A and B zones, however, it is evident from production as well as pressure data that communication from A to B Zone exists in some parts through presence of collapse features referred to as breccia pipes. The Bassein A and B Upper reservoirs share common gas-oil and oil-water contacts. The gas cap is housed primarily in the Bassein A zone, and the oil is largely in the Bassein B Upper reservoir.

The reservoirs are composed of a mixture of tight nodular limestone and highly altered limestone. While the diagenetic processes have extensively altered the B Zone resulting in porosities between 20% and 30%, these processes are less advanced in the A zone which have average porosities within pay intervals around 15%. The transient analysis, yields a typical permeability of 150-250 mD in the better reservoir quality areas and about 10-30 mD in the poorer areas for B zone. Also core measurements indicates low ranges of permeability in A-Zone when compared to the B-Zone where vertical to horizontal permeability ratio ($K_v/K_h$) is very high (>0.5).

As the vertical/horizontal permeability ratio is high, this reservoir is very much susceptible to coning resulting in inevitable increases in gas-oil ratio and/or water-cut. It, therefore, becomes imperative to properly design the well trajectories & plan the placement of the drain-holes to maximize productivity and reduce gas/water coning. Horizontal wells and
recently multi-lateral wells have been effective in minimizing the impact of coning in many areas of the field when produced under controlled drawdown.

Currently the field is being produced from seven wellhead platforms across the field with 75 plus producing wells, most of them horizontal and multilateral wells. It is essential to evaluate the performance of the current multilateral wells to optimize the productivity from these and the future wells to be drilled. Production logging, though challenging in horizontal wells in terms of both acquiring and interpreting the data, provides insight into flow behaviour of these wells. This paper discusses four case examples to highlight the operational challenges encountered in acquiring production logs in these horizontal wells and the problems faced in interpreting the data due to the complex flow pattern in the wellbore and the wellbore geometry per se. The paper also discusses in brief the history of horizontal well production logging in the field.

Earlier Campaigns

In 1999, a memory PLT survey programme using conventional sensors on 1 ½ inch coil tubing was carried out, but the campaign was only partially successful. 4 horizontal barefoot completed wells were attempted out of which complete survey could be done only in two wells because of the challenges of conveyance in open hole. Since a limited tool string consisting of only conventional sensors like Inline Spinner-Pressure-Temperature and Capacitance-Meter was deployed, the only results obtained were drawdown information and a qualitative idea about fluid entry zones. One key understanding from these two wells was that there seemed to be a very good correlation between the well trajectory and phase hold up / fluid entry zones as the Capacitance-Meter indicated hydrocarbon hold up at crests and water at troughs. Also the spinner response indicated gas entry at these crests. But these couldn’t be conclusively interpreted due to limitations of a single point phase hold up tool like Capacitance-Meter and a less sensitive inline spinner for mixture velocity measurement in a stratified flow regime.

In 2000, a tractor conveyed PLT campaign was carried out. The tractor was unable to negotiate the entire horizontal section of the drainhole in three wells and then the tool string got stuck in fourth well and got damaged. Thus, the operation had to be called off.

Further, in 2003 another MPLT Campaign on CT was planned in 4 wells to investigate the completion design and provide inputs for optimisation of future completion designs. This time, it was proposed to run multi-point multi-phase hold up tools for water hold up and gas hold-up measurements separately. However, the data acquisition was hindered due to challenging downhole environment at the heel of the horizontal openhole sections. On each occasion, the intervention of coil tubing was limited to physical obstruction rather the operating limits of the coil as predicted by the CT simulation. This could have been due to unconsolidated debris or washouts at the heel section of the drainhole just below the 9 5/8 inch casing shoe. The MPLT sensors and centralizers were found to be damaged on inspection after pulling out the toolstring. Thus, it was recommended that future completions need to incorporate slotted / segmented liner in the pay zone to enable any future well intervention work. This not only extends the depth of re-entry of coil tubing prior to friction lock-up but also prevents large unconsolidated debris form entering the completion.

To sum it all, the well conditions and the completion design were not conducive for conveyance of tools in the horizontal drainholes. The poor TVD control and available technology was posing a great interpretation challenge to determine the flow profiling of the horizontal section and identifying the specific fluid entry points. Also, if specific water/gas entry points were identified, the completion design did not allow any opportunity to isolate the sections.

New Completion Design

The old existing Panna horizontal well completion designs were reviewed and detailed studies commissioned to address the various problems being faced in Panna field. This resulted in a step change of completion design from existing bare foot/perforated tail pipe completions to segmented liner completions with capability to selectively isolate the segments contributing to water/gas encroachment. Figures 2 and 3 depict the old existing completions and the new Panna infill completion design respectively. The key features of new completion design are:

— Segmented liner (using a combination of sliding sleeves & swell type packers) with capability to isolate the drainhole sections
The tool-string conveyed using 1-1/2 inch coil tubing was run in memory mode. It comprised of the basic sensors namely, the Quartz Pressure, Fast Response Temperature, Inline Spinner, Full-bore Spinner along with the multipoint phase hold up tools DEFT* (Digital Entry Flow Imaging Tool) for water hold up and the GHOST† (Gas Hold Up Tool), for the gas hold up measurement. Readers wanting an in depth description of the principle of water hold up measurement using DEFT and gas hold up measurement using GHOST should refer to References (1), (6) and (8).

Case Examples

Out of the five well logged in the first phase of the campaign three case examples are discussed in this section.

Well A. This is a monobore horizontal well, completed in the Basein-B reservoir with a 5.5” segmented liner with six sliding sleeves and constrictors to isolate the flow sections. The well produced at a very high GOR since inception. Thus, the main objective was to determine the point of gas entry and isolate the same. The completion in this well consisted of external casing packers (ECPs) which isolate the gas bearing A-zone from the B-Zone. However, due to operational problems, the ECPs had to be inflated in a section where washouts were observed in openhole logs. Therefore, the prime suspect for the high GOR in the well was the integrity of the ECPs.

During the survey, the well was flowing at the choke size of 60/64” and producing about 250 BLPD at 23% water cut with 7 MMSCFD of gas. Before the flowing survey, one up and one down passes were recorded against the ECPs (interval: 2534-2600m MD) with the well shut-in for 24 hours to determine the leakage across the ECPs. After that, the well was put on production and three up and down passes were logged in the interval 2630-3260m MD. The Shut-in survey was carried out after the flowing survey.

From the passes taken across ECPs (2534-2600m MD) (Figure-4a.), it was observed that the temperature remains almost constant in the interval 2572-2598m MD although the TVD increases with MD across this interval. This suggested that some fluid, possibly gas is flowing behind the casing in this interval. This

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* Mark of Schlumberger
† Mark of Schlumberger
confirmed that ECPs, which were placed to isolate the gas bearing A zone from the B-Zone, were leaking and was the main reason for the high GOR since inception of the well.

The main observations during the flowing survey were (refer to Figure 4b):

1. Sliding sleeves at 3241 m MD (was kept closed during the survey) and 3123 m MD did not contribute to flow as indicated by spinner. DEFT and GHOST indicate the presence of gas and water as static fluid in this interval. However, the positioning of the GHOST and DEFT probes in the well bore cross section, does not allow us to conclusively determine any oil presence in this section.

2. Downstream of the SSD at 3093 m MD, GHOST and DEFT response together indicated presence of all the three phases viz. oil, water and gas. This coupled with increase in spinner and temperature at the same depth suggests an oil entry from the sliding sleeve at 3093 m MD.

3. Increase in spinner rpm and temperature at sliding sleeve at 2902 m indicate liquid contribution from this sliding sleeve. Increase in gas hold-up as indicated by GHOST could be because of change in trajectory from uphill to downhill in this section.

4. Against SSD at 2735 m MD, GHOST indicates all gas, DEFT shows all hydrocarbons and spinner shows an increase. The GHOST and DEFT response could be because of the downhill flow in this section. Taking into account all the sensor’s responses, it may be concluded that this sliding sleeve is contributing to the flow, though it is difficult to conclusively determine the type of fluid entry from this sliding sleeve.

5. Spinner increases at around 2680 m MD indicating an apparent fluid entry at this point. No sliding sleeves are present at this depth, which may suggest a leak in the casing at this depth. However, this may be an artefact of change in trajectory from downhill to uphill flow and also presence of a water leg at the trough as suggested by the hold up sensors.

6. At the 2655 m MD SSD, a significant decrease in temperature, substantial increase in spinner and 100 % gas hold-up indicated by GHOST even in the uphill trajectory suggest major gas production through this sliding sleeve, the entry point for the gas which channels down from the gas cap past the possibly failed ECPs.

Well B. This is a horizontal well with two lateral branches extending from the mother-bore and is completed in Bassein-B reservoir with a 5.5” segmented liner with six sliding sleeves and constrictors to isolate the flow sections. The well was logged at two flow rates of 3500 BLPD (1MMSCFD & 58% WC) and 4500 BLPD (1.6 MMMSCFD & 52% WC). There was no shut-in survey carried out in this well. The primary objective was to identify the water contributing sections and isolate the same by closing the associated SSDs.

Following major observations could be made from the two flowing surveys (refer to Figure 5a and 5b):

1. No flow below SSD at 2641 m MD as indicated by spinner and gas hold-up during both the surveys.

2. A distinct increase in water hold-up above SSD at 2641 m MD was observed on comparing the two flowing surveys. This coupled with spinner and temperature response suggested this sliding sleeve to be contributing water flow.

3. Major water entry from SSD at 2586 m MD (entry point for second lateral branch ML-2) as indicated by DEFT, GHOST, spinner and temperature responses.

4. Slight increase in spinner and water hold-up from DEFT indicates water contribution through SSD at 2507 m MD.

5. Major oil inflow through SSD at 2465 m MD (entry point for the first lateral branch ML-1) during both the surveys, as indicated by reduction in water hold-up, decrease in temperature and an increase in spinner. (Figure 5c)

6. No appreciable change in hold-up profile observed above and below the SSD at 2324 m MD, so the type of fluid entry through this SSD could be identified.

7. The difference in the bottom hole flowing pressure between the two flow surveys was observed to be ~ 3 psi which indicates a very high productivity. The estimated productive index for this well from the PL survey is ~ 400 bbl/day/psi.

Well C. This is a horizontal well with one lateral branch extending from the mother-bore and is completed in the Bassein-B reservoir with a 5.5” segmented liner with six sliding sleeves and constrictors to isolate the flow sections. The well was logged at two flow rates of 1800 BLPD (5.3 MSCFD and 10% Water Cut) and 2500 BLPD (8.2 MSCDF and 0% Water Cut) and in the shut-in condition.
The primary objective was to identify the gas contributing sections and isolate the same by closing the associated SSDs.

Major observations made from the passes recorded are (Figure 6a and 6b):

1. SSD beyond 2600m MD (not covered in the logging survey) seems to be contributing both oil and gas in the wellbore as indicated by spinner, GHOST and DEFT tool response.
2. Increase in spinner reading coupled with GHOST response indicates major oil contribution from SSDs at 2566m MD and 2303m MD.
3. No significant contribution was observed from SSD at 2450m MD.
4. Major gas entry from SSD at 2370m MD as indicated by a sharp decrease in temperature and increase in gas hold up.
5. It was observed that the drawdown was ~9 psi at the lower flow arte and ~14 psi at the higher flow rate. The estimated productive index for this well from the PL survey is ~200 bbl/day/psi.

Lessons Learnt

This set of PL surveys was the first successful production logging campaign in horizontal wells in Panna, a first of its kind in India. The complete production logging tool string was deployed in all the wells and good quality data was recorded. However, there were some major learning’s from the campaign which are highlighted below.

Operational Challenges

Firstly, the conveyance couldn’t be achieved till the planned depth. In fact, some of the SSDs could not be covered in three out of five wells surveyed. This was mainly due to the locking of the coil tubing due to increase in friction. The basic limitation of CT reach is its tendency to buckle due to friction between the coil and casing and this starts in a two-dimensional plane. Due to this, the friction forces increase further, forcing the CT into a corkscrew like shape and thus, the coil cannot be moved furthermore down-hole. It was felt at the time that tractor as a conveyance medium might mitigate this problem of reach as well as provide real-time data that would good quality data acquisition and also aid in quick decision making.

Another challenge faced during logging operations was the limited running-in speed of the oil in the horizontal section. Due to the limitation on coil size, speeds above 20 ft/min could not be achieved during down passes. Therefore, only up passes could be recorded at different speeds.

Interpretational Challenges

Production logging in horizontal wells often poses a challenge for interpretation mainly due to multiphase flow and deviation changes in the wellbore trajectory. A variety of flow patterns can exist in a horizontal wellbore due to varying deviation along the drainhole. In an upslope flow, the heavy phase flow is slower than the lighter phase and consequently the hold-up of the heavy phase is high and the lighter phase flows faster on the top side of the wellbore. And in a down slope, the lighter phase hold up is high and the heavy phase velocity is high. Also, as the spinner tends to lie on the bottom of the wellbore if not centralized properly, interpretation can be quite a challenge under such conditions. Also, the presence of water sumps due to ineffective clean-up at the troughs and oil / gas traps at crests can further add to the problem.

As the deviation data from the MWD (Measurement While Drilling) survey gives a record only every 30m, it can be difficult at times to explain hold up profiles as there could be local troughs/crests that are not captured in the deviation profile where there could be oil/gas traps or water sumps. So, it is advised to either run a deviation sensor (accelerometer) along with the string which can provide a continuous inclination of the borehole or use a gyro tool during the dummy run for the same purpose.

Also at times, one or more of the hold up probes can get clogged or one phase can get stuck to the probe tips which can cause inaccurate measurements and such anomalies need to be identified during QA/QC of data.

The sensors run in this campaign were not sufficient to provide an accurate quantitative flow profile in the drainhole with individual phase contributions. However, the data did provide some good qualitative inferences regarding the flow behaviour and oil/gas/water entry points in the wellbore.

PL Campaign Phase-II (Year 2006)

The Phase-II PL campaign was planned after a year when few more wells had been drilled. This time a wire line tractor conveyed PL
campaign was planned to overcome the challenges faced in the Phase-I campaign which employed CT. The electric line had to be a sour service cable as Panna field gas contains about 400-700 ppm of H₂S. The basic objectives of this campaign were similar to the Phase-I surveys but each well had its own customized diagnostic program to identify reasons for high GOR and high water cut.

Operational Challenges

Wireline Tractor (MAXTRAC‡) conveyed Production Logging was planned in 8 of the recently drilled infill wells. Initially four wells were attempted out of which PL survey was successful only in one well.

In the first well, the PLT string was conveyed downhole with 2 tractor sondes. The tractor was unable to negotiate the 7"x5.5" X-Over in the completion string (see Figure 9). The distance between the tractoring arms of the two sondes was 4 m, which was observed to be not sufficient enough to cross the Upper & Lower completion interface due to many ID profile changes over a small distance.

In the next well, the tool got held-up at the FBIV (Full Bore Injection Valve) a jewellery used in the completion string for reservoir isolation during integrity testing. While attempting to cross the FBIV, the cable developed a kink 6 to 12 inches above the rope socket due to excessive torque during conveyance across the valve, resulting in loss of electrical continuity (cable short). To address this issue the tool string was redesigned and the PL string was tractored down using three sondes to obtain better conveyance through wellbore sections with changing ID profiles like the FBIV, crossovers and sliding sleeves. Though the string did pass the FBIV this time, still the tractor was unable to cross the 7" to 5.5" cross-over due to possible debris in that section as inferred from the stalling of the tractor motor.

The third well was taken up next with PL string run on three tractor sondes, and this time the tractor was able to successfully tract the PL string down the cross-over and reach the planned depth. However due to mast height limitation gas hold-up tool had to be removed to accommodate the extra tractor sonde. The planned PL passes were recorded at 2 different flowing rates only. Shut-in pass was not recorded as tractor had to be pulled out for regular maintenance after 17,000 feet of tractoring. Though good quality data was recorded, the data without a gas-hold up measurement was insufficient to conclusively identify the gas influx points in the well. A brief discussion of the data recorded is included as a case example in the next section.

After servicing of the tractor and the PL tools, the campaign was resumed with the fourth well. The PL string was run with three tractor sondes and the tool got held-up at the 3rd SSD from the top. Cable once again lost its electrical continuity while attempting to negotiate the SSD. While pulling out of hole, the tool got stuck at the 2nd SSD. On flowing the well at a higher rate, the string got released and brought to surface. From the X-Y calliper records and damaged/missing probes of the GHOST and DEFT heavy debris on the lower side of the well bore is suspected (see Figure 8). The campaign was called-off midway, and it was decided to resume the operation after carrying out proper analysis of the problems and resolving the various issues.

Case Example

Well D. This horizontal well is completed with 5.5” liner with five sliding sleeves across the logging interval. During the PL survey, the well was flowed at two different flow rates of 900BLPD and 1400 BLPD. Major observations from these surveys were (Figure 7):

1. Sliding sleeves at 2978m MD and 2719.6m MD are the major contributors to the hydrocarbon flow in the well. This can be seen from the increase in spinner along with the DEFT hold-up image which indicates mostly hydrocarbons in the logging interval. As the GHOST could not be accommodated in the string, the nature of hydrocarbons could not be conclusively determined.

2. Percentage contribution from sliding sleeve at 2798m MD is so low that it is difficult to determine the exact nature of fluid entry. DEFT does not show any significant change in hold-up across the sleeve.

3. The sliding sleeve at 3044.7 m MD (Mother bore section) is contributing hydrocarbon to the total flow as indicated by spinner and DEFT images beyond sliding sleeve at 2978m MD. However, possibility of some water production along with the hydrocarbons cannot be ruled out completely.

4. From the pressure profile the drawdown in the well was calculated to be about 11 psi.

‡ Mark of Schlumberger
Lessons Learnt

Though tractor conveyance was considered as a better option over coil tubing conveyance for the reasons discussed earlier, the surveys could not be completed successfully due to various operational issues. There were a few key lessons learnt during the second phase of the production logging campaign which are as under:

**Cable-Kink.** The sour service cable used was stiffer than the normal cable and due to tension variations in the course of many manoeuvres while tractoring down changing ID profiles in the completion, the cable tends to torque and develop a kink, even with a swivel in the string. This leads to a loss of electrical continuity in the cable posing a further risk of not being able to operate the electrical release weak point in case of tool stuck up. After the first failure, the procedure was revised to address the problem by keeping the cable in tension especially at the cable head at all times and use three tractor sondes for better conveyance but still, the similar failure recurred. It is suggested that a normal cable may be used instead of a H2S service cable in this downhole environment, however, this cable would have to be discarded after the campaign as it would lose its strength.

**Wellbore Environment.** The tool string could not be conveyed down smoothly in the horizontal section in the last well attempted and got held up due to debris in the wellbore. The presence of debris can be confirmed from the X-Y calliper readings which showed difference in the X and Y calliper readings up to 1.25 inches in the 5.5” liner (see Figure 8). Also, when the tool was pulled out of hole, it was observed that the tractor arms were not fully closed due to debris between the tractor arms and the tool body. This problem could be addressed by proving the hole and cleaning the wellbore off debris using coil tubing prior to running the PL string.

**Tractoring through the Upper & Lower completion interface.** It is proved that with the deployment of 3 tractor sondes, the tool string can be successfully conveyed across the 7” x 5.5” crossover interface. It is also suggested that an option of using a deployment bar (to be connected between the tractors) may be looked into so as to increase the distance between the two sondes. This would facilitate a two sonde conveyance system instead of three.

PL Campaign Phase-III: The Way Ahead

As it was recognised that the risk of PL string getting stuck is significant due to the presence of debris, this must be cleared prior to PL survey. This can be achieved by carrying out a well bore clean up using coil tubing. This procedure is expected to minimize friction, mitigate the problem of well debris and pave way for a smooth, hitch-free data acquisition. The third phase of PL surveys is planned to be carried out using coil tubing, immediately after a horizontal drainhole cleaning exercise. Though there are some downsides envisaged like not being able to survey till the end of the drainhole using coil tubing, there are other advantages in terms of cost and logistics and also a higher chance of success as observed during the Phase-I campaign.

Conclusions

This set of memory PL surveys was the first successful production logging campaign in horizontal wells in Panna, a first of its kind in India where the complete production logging tool string including the new generation multi-point multiphase hold up tools was deployed and good quality data was recorded. The new completion design has made it possible to successfully carry out well intervention and data acquisition in horizontal well bores which was earlier, a big challenge in Panna. Though all the objectives were not met due to operational and interpretation challenges, the production log data has been very valuable in evaluating the performance of these new infill multilateral wells and has given great insight in optimizing productivity from these wells and in improving the reservoir management strategy on the whole. The results of the production logging campaign will not only enable current well production optimisation, but may impact future well and completion design. Moreover, the results can be utilized to calibrate our dynamic reservoir simulation model giving us a more reliable predictive tool.

The major lessons learnt from the campaign has to be kept in mind while planning the future surveys using the latest technological improvements and better practices as production logging is an indispensable tool in managing a thin oil rim reservoir like Panna.
Acknowledgement

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References


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Figures

Figure 1a – Location Map

Figure 1b – Structural Cross Section

Figure 2 – Previous Barefoot completions (Openhole / Tailpipe /Perforated pipe)
Figure 3 – New Completion Design

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Gas hold-up in down-slope

Oil presence inconclusive due to position of probes

Caliper indicating SSD

Liquid hold-up in upslope

Gas Entry from 1st SSD

Figure 4b - Flowing Survey in Well A

Stratified flow of Gas, Oil & Water
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Figure 5b - Flowing Survey 2 in Well B
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- Water hold up increases in the Flow Survey 2
- Stagnant Gas at high Altitudes during both flow surveys

Flow Survey 1
Flow Survey 2
**Figure 6a** - Flowing Survey 1 in Well C

**Figure 6b** - Flowing Survey 2 in Well C
Figure 7 - Flowing Survey in Well D

Figure 8 - Caliper Log indicating debris in the wellbore
**Typical Panna Completion Schematic**

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<tr>
<td>2</td>
<td>TRSSSV 4 1/2” NSCT Box x Pin</td>
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*Figure 9 - Typical Panna Horizontal Well Schematic*